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Investigation of Transient Thermal Performance of Parabolic Trough Solar Collectors in Different Climatic Conditions

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Abstract:

Parabolic Trough Collectors (PTCs) are widely used in solar thermal applications due to their high efficiency in concentrating solar radiation This study presents the design and transient thermal analysis of a parabolic trough collector (PTC) using SolidWorks 2024 for 3D modeling and Ansys 2024 R1 for simulation. The collector consists of a copper alloy for the absorber tube, aluminum alloy and bronze for the collector structure, and glass panels for thermal insulation. The thermal performance of the system is evaluated under boundary conditions with reflector temperatures set at 40°C, 44°C, and 47°C. The transient thermal analysis investigates heat transfer characteristics and efficiency to optimize energy absorption and system performance. The results provide insights into material selection and thermal behavior, aiding in the enhancement of PTC systems for solar energy applications. The heat transfer characteristics of the system are analyzed using finite element simulations to determine temperature distribution, heat flux, and efficiency variations over time.

Keywords: PTC, SolidWorks, Ansys 2024 R1

1. INTRODUCTION

The sun is a never-ending source of energy. Every day, the sun provides untold amounts of solar energy to the planet, the majority of which is in the form of light. Following the rapid rise in oil costs in the 1970s, various countries began to create extensive solar energy research and development programmes The most readily available form of energy is solar energy. It is also the most essential of the non-conventional energy sources because it is non-polluting and thus helps to reduce greenhouse gas emissions. For usual tasks, solar light can be a free source of renewable energy. Solar energy substitutes the consumption of electricity or fossil fuels. Solar water heating is a method for reducing dependence on conventional water heating systems is of its kind. Solar water heating effectiveness is developing as a result of extensive research. Solar collectors are the key component of active solar-heating systems They gather the sun's energy, transform its radiation into heat, then transfer that heat to a fluid (usually water or air). The solar thermal energy can be used in solar water-heating systems, solar pool heaters, and solar space-heating systems The increasing global demand for sustainable energy, solar thermal power has emerged as a promising alternative to fossil fuels. Among the various solar thermal technologies, the Parabolic Trough Collector (PTC) is one of the most widely used systems for concentrated solar power (CSP) applications. It efficiently captures and converts solar radiation into heat energy, which can be utilized for electricity generation, industrial heating, and desalination.

Parabolic Trough Collector:

- To focus the sun's beams on the reception tube, the parabola trough uses a series of concave mirrors. These valleys can rotate around a single axis, usually north to south, to follow the Sun and maximise efficiency. This tube absorbs concentrated solar energy, which is used to heat the fluid as it travels through it.
- To reduce the extreme temperatures generated by the mirrors, a synthetic oil or molten salt mixture is often circulated via the heat exchanger tubes. The typical temperature range for heating this fluid is between 400–600∘C. Once the oil is in the tubes, the procedure can proceed.

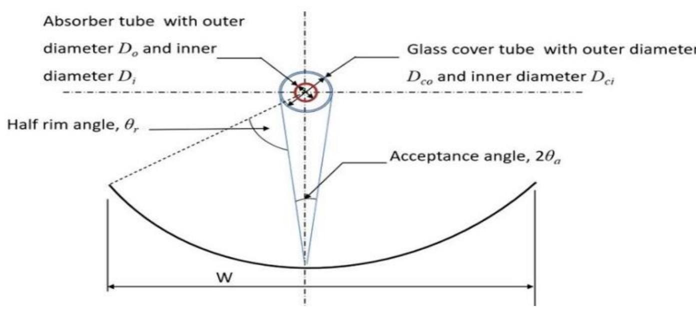

Figure 1: Diagram of Solar Parabolic Trough Collector

Scope of work

- Renewable energy resources need to enhance the applications in various industries and households, solar energy utilization growing day by day the present work have a broad scope to basic analysis for future.

2. Literature Review

Madan [1] Designed and produced a solar-powered cylindrical water warmer. High-quality glass was rolled into a cylinder, and a copper coil tube with spiralling rings painted black acted as a collector for the sun's rays striking the glass. Helal et al [2]. established the geometrical features of an integrated collector stack (ICS) with a single horizontal cylinder tank housed in a reflector with three parabolic arms. This setup was compared to two other solar water heating systems: one with an asymmetric CPC tank and the other with a symmetric CPC tank. [3] Mohammed developed a parabolic dish solar water heater for use in heating water for household use. An automatic electrical control circuit was created to ensure the design's optimal functionality. The water heater only heats up to roughly 10 litres at a time so as to conserve valuable floor space.. Pei et.al [4]. A series of tests were conducted in Hefei, China, to determine the efficacy of using a mini-CPC reflector in conjunction with an evacuated tube solar water heating system. In order to compare and contrast their thermal performance, the first and second laws of thermodynamics were applied. Data was collected for two days to examine the performance of two different solar water heating systems. Singh et al [5]. investigated the feasibility of producing hot water using solar thermal technology. The parabolic trough concentrator (PTSC) consisted of an aluminium sheet wrapped in cloth to which rectangular mirror strips were bonded. Oggy Et.al [6]. constructed a solar water heater using off-the-shelf materials for a home. The solar energy is absorbed by a flat-plate collector, which consists of an absorber plate, a grid of fluid-carrying tubes underneath, an insulated covering with a see-through glass cover, and an integrated cold and hot water tank. Pachkawade Et.al [7]. The cost and size of a solar water heater can be reduced by substituting less expensive and more easily accessible materials, such as plastic lateral tubes, HDPE pipe, old glass wool, thermocol, plastic barrel, G.I. sheet collect or boxes, for more expensive and less easily accessible alternatives. [8] Macedo- Valencia et.al. presented an article that discussed the process of developing a parabolic trough collector (PTC) to heat water as a proof-of-concept model.

3. METHODOLOGY

A Parabolic Trough Collector (PTC) is a solar thermal device that captures and concentrates sunlight onto a receiver tube placed at its focal point. The collected heat is transferred to a working fluid, which can be used for power generation, industrial heating, or desalination applications. This methodology outlines the design, modeling, and transient thermal analysis of a PTC system.

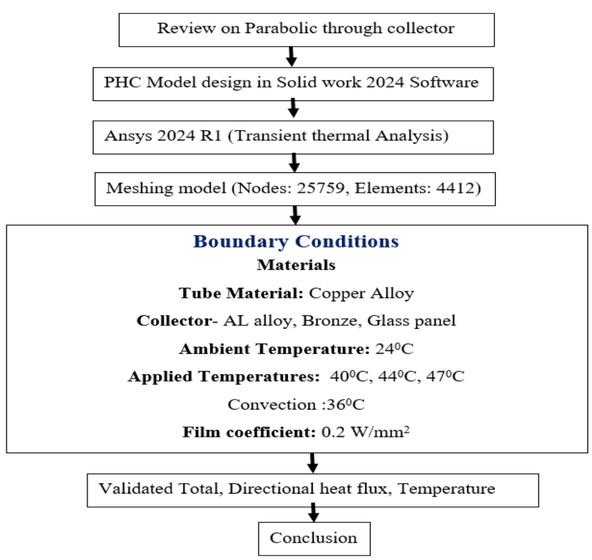

Figure 2: Design flow chart

The collectors designed as parabolic troughs focus sunlight in a single direction, called the focal line. These collectors see widespread industrial use for producing electricity. The solar array accounts for about 37% of the entire price tag. An important step towards making solar thermal power plants financially viable is decreasing the price of solar thermal collectors.

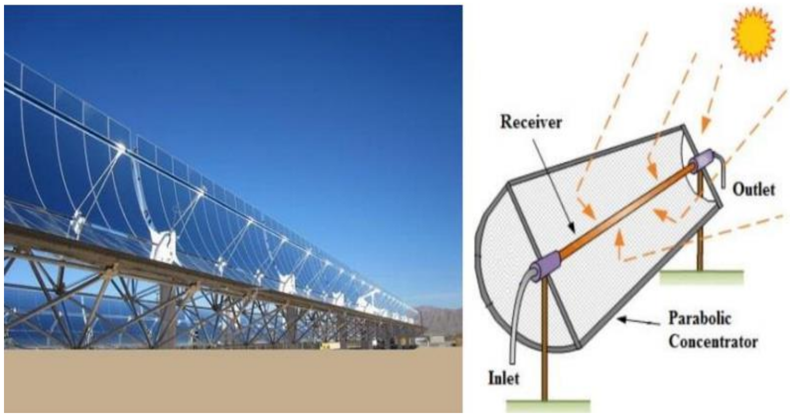

Figure 3: Parabolic Trough Collector

- Heat transfer within a water-flowing pipe is the focus of this investigation into a parabolic solar collector. In the current configuration, a solar panel is placed on top of a water pipe.
- A parabolic plate serves as the solar radiation absorber plate, located behind the tube to collect and concentrate the sun's rays for later use. Parabolic solar collectors work in this way.
- To reflect this, the wall of the flow pipe is segmented into an upper and lower section. The sun warms the upper portion of the wall as it rises.
- However, the parabolic absorber plates of the collector affect the lower part of the wall.

DESIGN PARAMETERS:

A parabolic trough collector's design parameters fall into two broad categories: geometry and function. The concentration ratio, receiver diameter, aperture width and length, rim angle, focal length, and receiver diameter are all important geometric elements of a PTC.

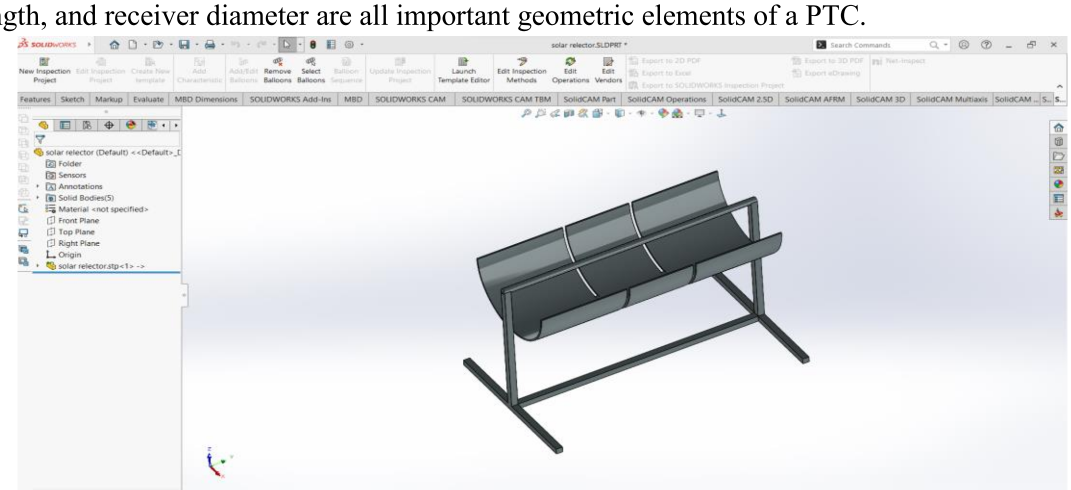

Figure 4: Design model PTC

4. RESULTS AND DISCUSSIONS

In their study to parabolic trough solar collectors, there have been insufficient studies to determine three-dimensional temperature distributions. To further understand the temperature distribution, we investigate the impact of continuous solar radiation on a parabolic trough collector. The simulations are executed using ANSYS 2021R1.

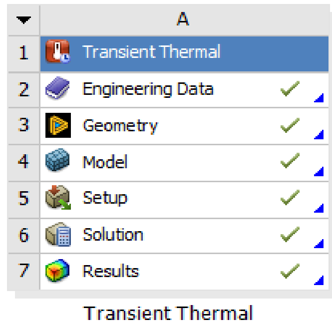

Figure 5: Ansys layout

Transient thermal Analysis:

Transient thermal analysis is the study of how a system reacts over time to both constant and changing boundary conditions. It is possible to calculate the time required to obtain a steady state temperature under constant boundary conditions, as well as the maximum period that operating circumstances can be maintained until a critical temperature is reached.

- The graph shows initial conditions: As emphasized before, the graph shows initial temperatures and heat flux values. It does not show the transient behavior or the steady-state temperatures that will be reached.
- 40 Degrees: The "Temperature (0^0C)" bars on the graph are at approximately 40°C. This is likely the initial temperature of the materials before the PTC heater is activated.
- 44 and 47 Degrees: You're asking about the transient behavior at 44 and 47 degrees. The graph doesn't show any information about what happens at 44 or 47 degrees.

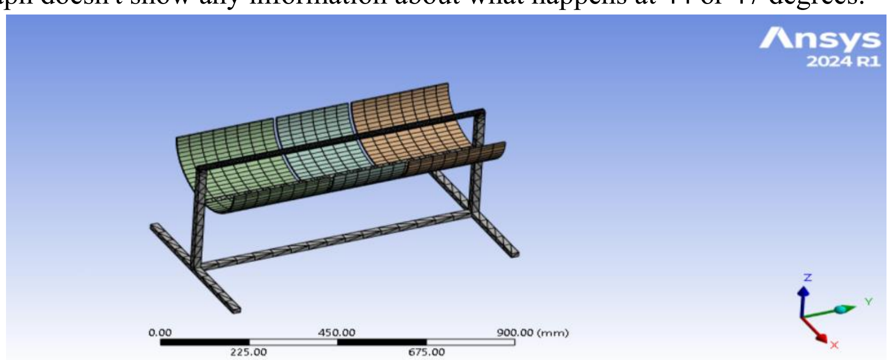

Figure 6: Meshed model

Transient thermal analysis Using bronze material PTC at 40^0C:

When performing a transient thermal analysis using bronze material with a PTC (Positive Temperature Coefficient) heater at 40°C,To essentially simulating how the temperature of the bronze object changes over time due to the heat input from the PTC heater

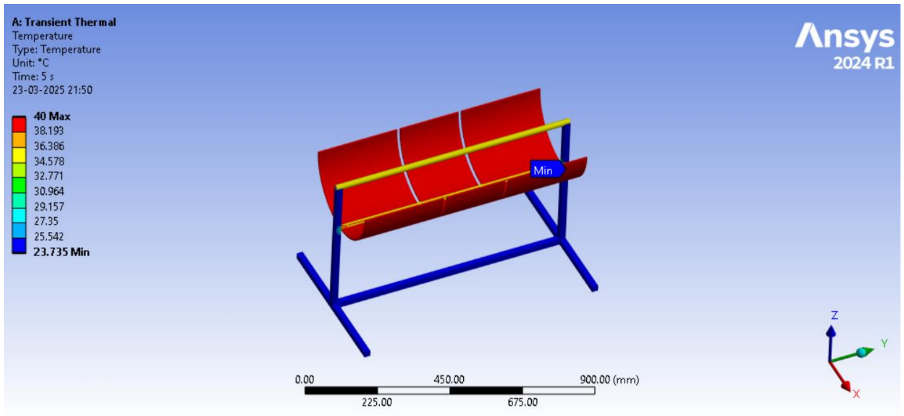

Figure 7: Temperature

The simulation of the Parabolic through collector is done during the study and the results obtained are discussed in the following section. The figure shows the temperature variation across the receiver and the collector surface. The maximum receiver surface is found to be 40^{0}C temperature remains constant and middle of the Aluminum tube was slide reflected the heat at PTC surface

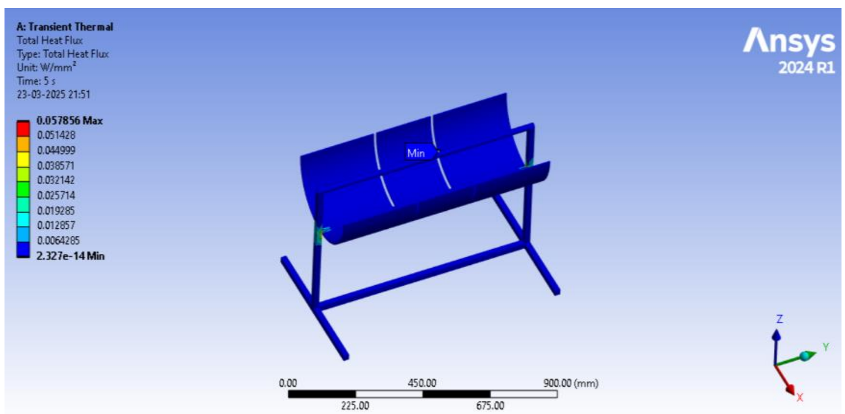

Figure 8: Total heat flux

The figure shows the Total heat flux variation across the receiver and the collector surface. The maximum receiver surface is found to be 5.7856e-002. the absorber while the collector surface found to 40^{0}C temperature remains constant.

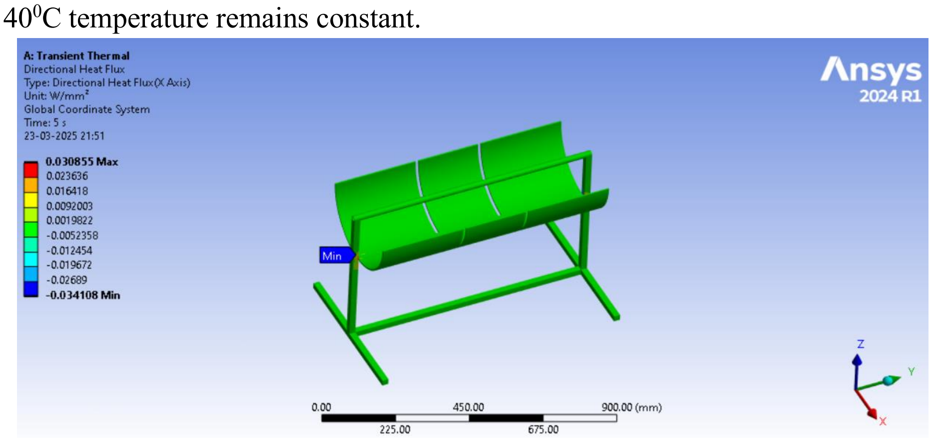

Figure 9: Directional heat flux

The figure shows the Directional heat flux variation across the receiver and the collector surface. The maximum receiver surface is found to be 3.0855e-002. the absorber while the collector surface found to 40^{0}C temperature remains constant.

Transient thermal analysis Using bronze material PTC at 44^{0}C:

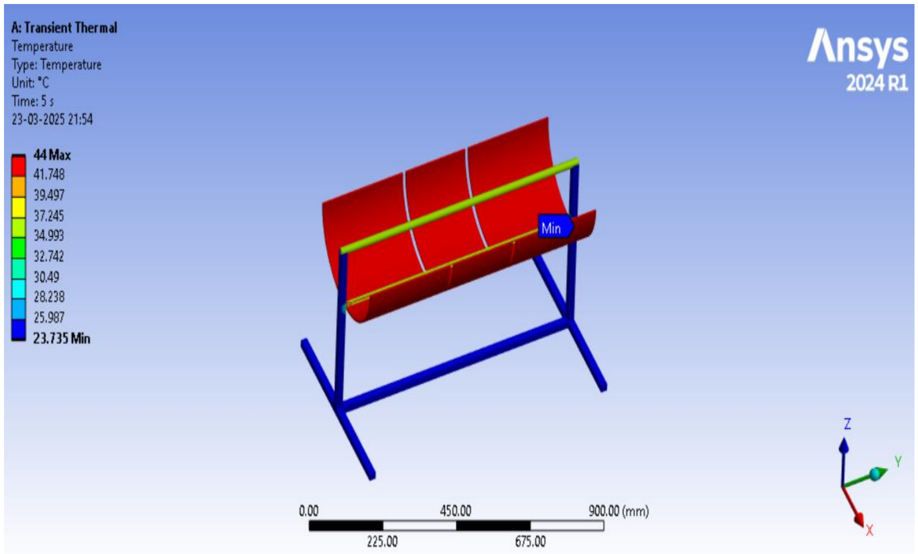

Figure 10: Temperature

The simulation of the Parabolic through collector is done during the study and the results obtained are discussed in the following section. The figure shows the temperature variation across the receiver and the collector surface. The maximum receiver surface is found to be 44 ^{0}C temperature remains constant.

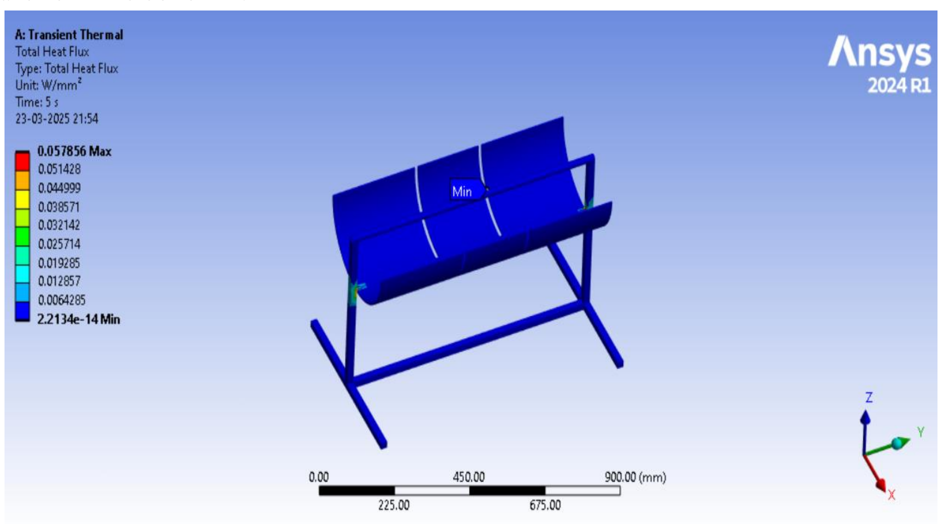

Figure 11: Total heat flux

The figure shows the Total heat flux variation across the receiver and the collector surface. The maximum receiver surface is found to be 5.7856e-002. the absorber while the collector surface found to 44^{0}C temperature remains constant.

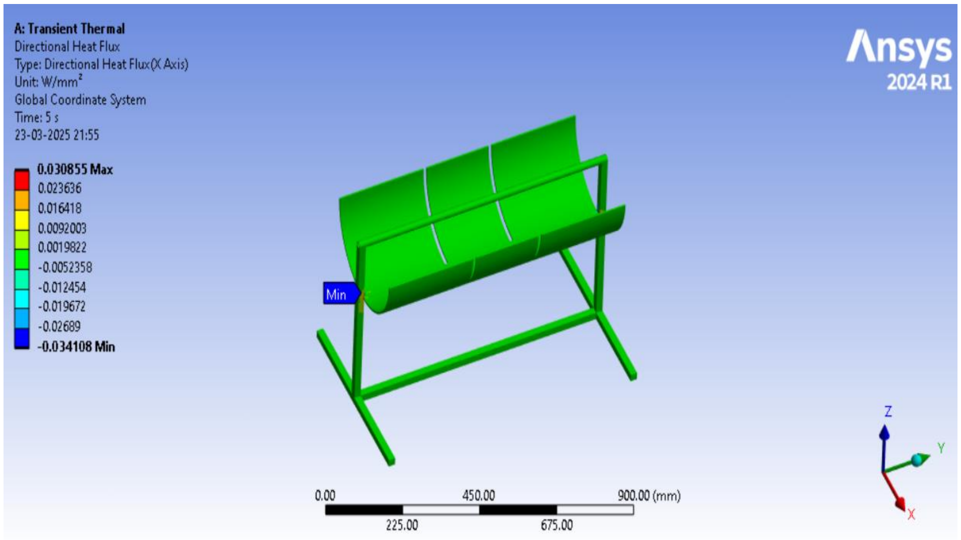

Figure 12: Directional heat flux

The figure shows the Directional heat flux variation across the receiver and the collector surface. The maximum receiver surface is found to be 3.0855e-002. the absorber while the collector surface found to 44^{0}C temperature remains constant.

Transient thermal analysis Using bronze material PTC at 47^{0}C:

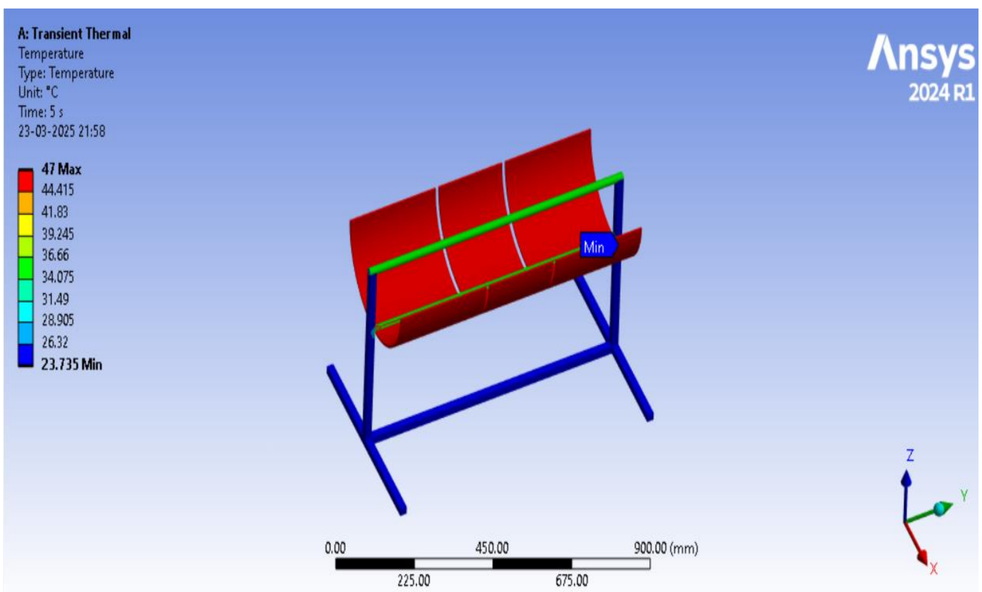

Figure 13: Temperature

The simulation of the Parabolic through collector is done during the study and the results obtained are discussed in the following section. The figure shows the temperature variation across the receiver and the collector surface. The maximum receiver surface is found to be 40 ^{0}C temperature remains constant and middle of the Aluminum tube was slide reflected the heat at PTC surface

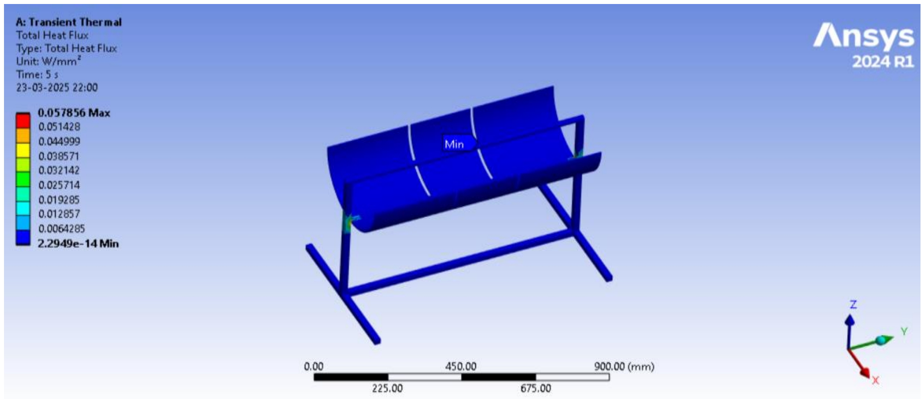

Figure 14: Total heat flux

The figure shows the Total heat flux variation across the receiver and the collector surface. The maximum receiver surface is found to be 5.7856e-002. the absorber while the collector surface found to 47^0C temperature constant.

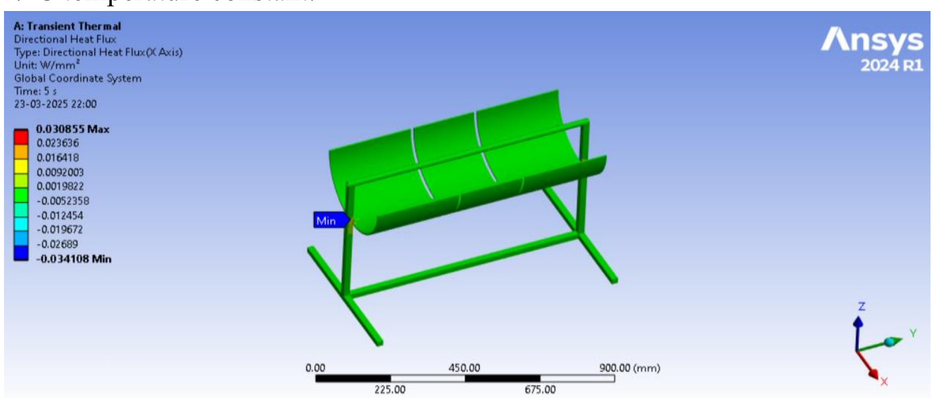

Figure 15: Directional heat flux

The figure shows the Directional heat flux variation across the receiver and the collector surface. The maximum receiver surface is found to be 3.0855e-002. the absorber while the collector surface found to 47^0C temperature remains constant.

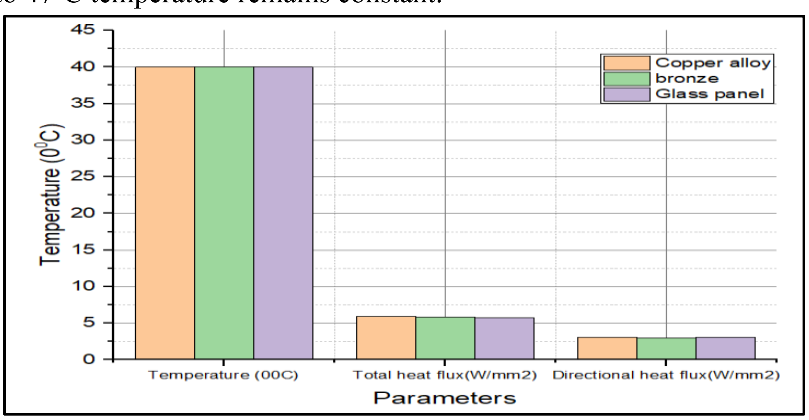

Figure 16. PTC Maximum temperature variation at 40^0C at different materials

The figure compares the behavior of copper alloy, bronze, and glass panel materials in terms of temperature, total heat flux, and directional heat flux under the influence of a PTC heater. The materials start at 40°C, which is likely the ambient temperature before the PTC heater is activated, and the label "Temperature (0°C)" appears to be an error. The total heat flux values are around 6 W/mm² for all materials, indicating a similar capacity for heat conduction and comparable rates of heat transfer. The directional heat flux, with values around 3 W/mm², suggests that the heat flow is uniformly distributed across all materials, rather than being strongly directional.

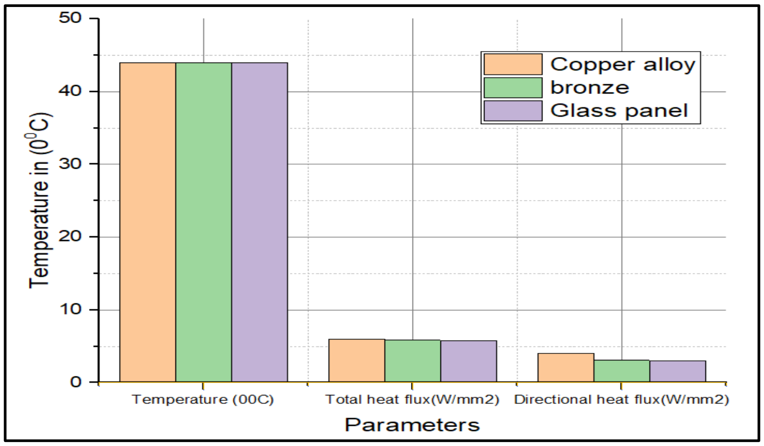

Figure 17: PTC Maximum temperature variation at 44^{0}C at different materials

The figure shows the initial temperature (likely ambient) and heat flux values before the materials reach a steady-state temperature under the influence of the PTC heater. However, it does not provide the "maximum temperature variation" at 44°C. In summary, it does not provide enough information to determine the maximum temperature variation at 44°C, instead focusing on the initial conditions and heat flux values before the materials stabilize.

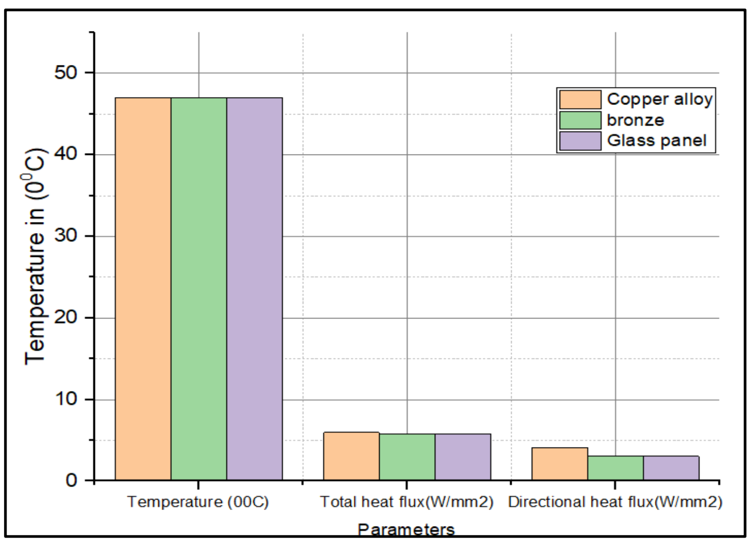

Figure 18: PTC Maximum temperature variation at 47^{0}C at different materials

The figure shows the initial temperature (likely ambient) and heat flux values before the materials reach a steady-state temperature under the influence of the PTC heater. It does not reflect the "maximum temperature variation" at 47°C. The "Temperature (0°C)" label is misleading and should likely indicate the initial or ambient temperature. Overall, the graph highlights the similarity in the initial heat transfer characteristics of the three materials.

CONCLUSION

The transient thermal analysis of the PTC demonstrated efficient heat absorption and transfer characteristics under different environmental conditions. The choice of materials played a critical role in optimizing performance. The results indicate that:

- The copper alloy tube effectively conducted heat, ensuring efficient thermal energy transfer.
- The Aluminum alloy collector provided structural support while maintaining lightweight properties.
- The glass panel reflector enhanced solar energy concentration, maximizing thermal efficiency.

This study provides insights into optimizing PTC designs for improved performance in solar thermal applications. Further research can explore additional coatings and insulation techniques to minimize heat loss and enhance efficiency.

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